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Monitoring of Odonata in Britain and possible insights into climate change

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Abstract

The history of recording and monitoring of Odonata in Britain is briefly described. Results are then presented which suggest that the country's Odonata fauna is currently in a period of flux, in a manner consistent with the actions of a high-level regulatory factor such as climate change. The ranges of many resident species are shifting. *Leucorrhinia dubia* has recently been lost from southern England, but many species are presently expanding their ranges to the north and west, some (such as *Aeshna mixta* and *Anax imperator*) with considerable speed. In addition to these changes, a number of 'southern' species have started to appear in Britain for the very first time. These include *Lestes barbarus*, *Erythromma viridulum* (which has now become a locally-common resident in southeast England), *Anax parthenope* and *Crocothemis erythraea*. In addition to these distributional changes, some recent trends in flight times are also discussed. Evidence indicates that many species are now emerging significantly earlier than in the past, though trends relating to the end of the flight period are less clear cut.

Keywords

Climate Change, Odonata, dragonflies, monitoring, distribution, range expansion, 'Mediterranean species', migration, phenology, emergence dates

Introduction

The study of Odonata in the British Isles goes back a considerable time; several publications devoted at least in part to dragonflies appeared as early as the end of the 18th century. These included "An exposition of English insects" (Harris 1782) and "The natural history of British insects" (Donovan 1792–1813). Interest in Odonata was

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however never as great as that for groups such as birds, flowers or Lepidoptera, and it was not until the time of W.J. Lucas that much in the way of centralised distributional data became available. In his key book (Lucas 1900), Lucas listed the then known localities for each species on a county basis. Cynthia Longfield (Longfield 1937, 1949), later assisted by Norman Moore and Philip Corbet (Corbet et al. 1960) continued to update the available distributional data. Structured monitoring of dragonflies within the UK was finally formalised in 1967, with the establishment of the Odonata Recording Scheme under the auspices of the national Biological Records Centre at Monks Wood, and the first high-detail distribution maps started to become available (e.g. Hammond 1977, 1983). These events partly reflected, but to an even greater extent induced, a substantial increase in the popular observation of dragonflies - a trend that still continues today. In 1983 the British Dragonfly Society (BDS) was formed, and after a period of intense field observations a national Atlas (Merritt et al. 1996) was produced, dealing with observations up to, and a little beyond, 1990. At about this time administration of the Odonata Recording Scheme was formally devolved to the BDS, but the last year or two has then seen something of an extension into a more centralised organisation with the development of the National Biodiversity Network (NBN). This aims to facilitate the exchange of biological information of many sorts by making a wide range of biological records readily available to all over the internet (see the NBN Gateway at http://www.searchnbn.net/). The BDS has been closely involved with this scheme from the start.

Clearly there is a long history of recording Odonata in the British Isles, and although the volume of the older data is perhaps not as great as that for some other biological groups it still provides much useful background information. Coupled to the well-developed modern recording and monitoring scheme, sufficient data is now available to make it relatively easy to detect changes to the region's dragonfly fauna and allow some investigation of the underlying causes. Indeed, with the current BDS membership standing at roughly 1500 (although admittedly not all will be highly active in the field), Britain must be one of the most intensively-recorded countries in Europe, if not the world, as far as Odonata are concerned. In this article many recent developments are described and the possible role of climate change is discussed. In Britain, climate change, whatever its underlying cause, would appear to be very much a reality, with the standardized annual mean Central England Temperature (Manley 1974) having exceeded the 1961–1990 average during nineteen of the last twenty years (Hadley Centre 2008). In England, six of the seven warmest years on record (going back as far as 1659) have also occurred since 1995 (Hadley Centre 2008). Currently, the averaged CET anomaly stands at very nearly +1.0°C (Hadley Centre 2008).

Species recorded from the British Isles

One of the most obvious ways in which a country's Odonata fauna can be affected by climatic conditions is by the direct influence on what species can maintain a presence.

Three species have become extinct in Britain during the last 60 years, *viz. Coenagrion armatum* (last seen 1958; Brownett 2005), *C. scitulum* (last seen 1952, Merritt et al. 1996), and *Oxygastra curtisii* (last seen 1963, Merritt et al. 1996). All three were at the then limit of their European range, and had extremely localised distributions even at their peak, so that they all eventually succumbed to habitat degradation of one form or another. These were thus probably 'chance' events. It is however worth noting that *C. scitulum* was only ever recorded during the period 1946–1952, and it seems possible that it was only a transient resident, initially colonising during the good migrant years of the 1940s (Longfield 1949; Parr 1996) that also saw a number of unusual records from the Channel Isles (Silsby and Silsby 1988).

With the exception of the extinctions listed above, the British Odonata fauna remained relatively stable for an extended period of time. As with many other countries in northern Europe, the last few years have however seen the arrival of a substantial number of new species, many of them having their strongholds in the Mediterranean region. *Erythromma viridulum* was first observed in 1999 and colonised rapidly, with it now being a locally-common resident in SE England (Parr 2004, 2005). *Lestes barbarus* was first observed at a single site in Norfolk during 2002, with records from there and at another site in coastal SE England during 2003 and 2004. Despite thorough searches, the species was not however noted at these sites in subsequent years, although a single individual was found at a third, inland, site in 2006 (Parr 2007). As far as Anisoptera are concerned, there was an unconfirmed report of *Anax parthenope* in the mid 1980s, though it had to wait until 1996 for a substantiated record to be forthcoming. Since then the species has been seen annually, with several hundreds of individuals now having been recorded; during 2000 one even reached as far north as 59°17'N (Parr et al. 2004). Most sightings of *A. parthenope* currently seem to refer to migrants, but successful breeding has been proven at two sites in the southwest (Jones 2000), and has been strongly suspected from several further areas. Confirming that the situation is still evolving, during 2006 record numbers were seen, with ovipositing being reported from at least 5 sites (Parr 2007). Other dragonflies added to the British List in recent years include *Sympetrum pedemontanum* - with one record in 1995 and another 'possible' seen by a member of the public in 2003 (Parr 2004) - and *Anax junius*, where the first European records of this Nearctic species were made in southwest England during autumn 1998 (Pellow 1999). In addition, *Crocothemis erythraea* has also started appearing in Britain in recent years, with 6 records in England since the first sighting in 1995. These records principally refer to single males seen near the south coast (no females have as yet been definitely observed), though there was an unexpected sighting of a sub-mature male in Cumbria, at very nearly 55°N, during 2004 (Parr 2005). Finally, although not strictly directly related to the British mainland, it is worth noting that *Orthetrum brunneum* was recorded for the first time ever from the Channel Isles (on Guernsey) during 2001 (Parr 2002).

In addition to the occurrence of new species, the frequency of appearance of certain more 'normal' migrant species also appears to be changing. *Sympetrum fonsco-*

lombii was for many years regarded as only an erratic visitor to British shores, often apparently being absent for several years in a row (Longfield 1949). In the late 1980s and early 1990s fairly regular records started to come from southwest England, and the species is currently regarded as an expected and often not-uncommon migrant to Britain, with major influxes having been noted in 1996, 1998, 2000, 2002 and particularly 2006 (Parr 2003, 2007). Successful breeding is now also regularly reported (e.g. Parr 2002, 2004, 2007). Although the recent increase in numbers of active recorders must complicate interpretation, observed changes do seem to be real. Thus the related *S. flaveolum*, a migrant of more easterly rather than southerly origin, shows a very different trend to its pattern of records (Parr 1996, 2003).

Range expansions and contractions for resident species

One of the advantages of the relatively long history of dragonfly monitoring in Britain, and its focus on distributional aspects, is that it is now feasible to sensibly analyse range changes of the resident species. As with other countries in northern Europe, it is clear that many species are currently undergoing significant changes to their range. These are mostly expansions, typically to the north and west, but a few species do seem to be contracting their range. Hickling et al. (2005) have provided an overview of changes seen over the period 1960–1995, but there are problems in interpreting some of the data and events have also progressed since the time period they cover. It may thus be worthwhile describing further certain species for which range changes are being seen:

Calopteryx splendens. There is evidence for a recent strengthening and range expansion of the more northerly sub-populations in Britain (Clarke 1999; Ward and Mill 2004), especially since 1990. The role of possible improvements in water quality however remains to be evaluated.

Brachytron pratense. This species declined or disappeared in several areas during the post-World War II period, perhaps in part due to pollution and changes in land use associated with an intensification of agricultural practices. A recovery described by Merritt et al. (1996) and Perrin (1999) has continued, and there have been records from many new areas in recent years. To some extent there has simply been an infilling of range, but in addition there seems to have been an extension into western parts of Wales. The species has also been recorded from a few southern and western areas of Scotland since 1984 (Smith and Smith 1984; Merritt et al. 1996), though may perhaps have been overlooked there previously, since Sélys (1846) reported being shown a specimen from the region.

Aeshna mixta. In older times this species was essentially a scarce immigrant to Britain, though there is circumstantial evidence that it may have been temporarily established in East Anglia at the end of the 19th century (Mendel 1992). A large invasion during 1935 saw records from several areas of southeastern England, and somewhere around this time it apparently started to become increasingly established as a resident

(Mendel 1992). Merritt et al. (1996) describe the gradual expansion of the species throughout southeast and central England up until 1990. Since then range expansion has continued, and seems to be increasing in rate. The species reached Ireland in small numbers during 2000 (Nelson and Thompson 2004), and is now established there, while the first confirmed records for Scotland were in 2004, with reports from at least three sites, one of which was well to the north (Parr 2005).

Aeshna isoceles. In the 19th century this species was found in a few widely-scattered fenland localities throughout East Anglia, but became restricted to the Broadland area of Norfolk and the immediately adjacent part of Suffolk as a result of habitat loss (Merritt et al. 1996). This highly localised distribution warranted the species being afforded legal protection under the Wildlife and Countryside Act 1981. In the 1990s, individuals began to be seen on the Suffolk coastal strip, and ovipositing has been observed here in the last few years. Although these sites are not a great distance from prior strongholds (up to 30 km), the move into a new habitat is of some significance for such a rare and localised species in Britain. Interestingly, while at most of its Norfolk sites the species is apparently associated with the presence of Water Soldier *Stratiodes aloides*, this is not the case in coastal Suffolk. The relationship between this range expansion and the occasional record on the east coast of what might be immigrants of Continental origin (Parr 2004) remains to be established.

Anax imperator. As with *Aeshna mixta*, this is another common species that is now rapidly expanding its range (see Fig. 1A). Before 1982 there were very few records north of 52°55'N, and those mostly referred just to isolated individuals. By the early 1990s the species had however been found in Cheshire and Lancashire, north to about 53°45'N (Merritt et al. 1996), and good populations now exist in these areas. By 1995 it had reached Cumbria (Clarke 2004), and by 2003 records for Scotland (at *ca*. 55°00'N) were forthcoming (Parr 2004). It was first seen in Ireland during 2000 (Nelson and Thompson 2004), and now appears to be established there.

Libellula depressa. Long established in southern Britain, this species has been increasingly noted further north in recent years. The northern limit of its range was at roughly 53°30'N in 1990 (Merritt et al. 1996), but a wanderer or migrant reached very nearly 56°N in Scotland during 2003 (Parr 2004).

Libellula fulva. This species has always been very local in Britain, where it has the vernacular name of Scarce Chaser. Merritt et al. (1996) describe a distribution centred on roughly six scattered river systems and nearby still-water sites in southern and southeast England. The last few years have however seen a number of new areas being discovered (Parr 2005, 2006), including records from an additional four counties. Some of these new sites are up to 100 km away from previously known sites, and extend the overall range to the west and northwest.

Orthetrum cancellatum. This was once at best a rare and localised species in southern England, but in the 20th century *O. cancellatum* became increasingly more widespread and common, perhaps in part due to the spread of flooded gravel workings, which provide excellent habitat (Merritt et al. 1996). Range expansion in both Britain and Ireland has since continued, and a hot weather-related movement during late July/

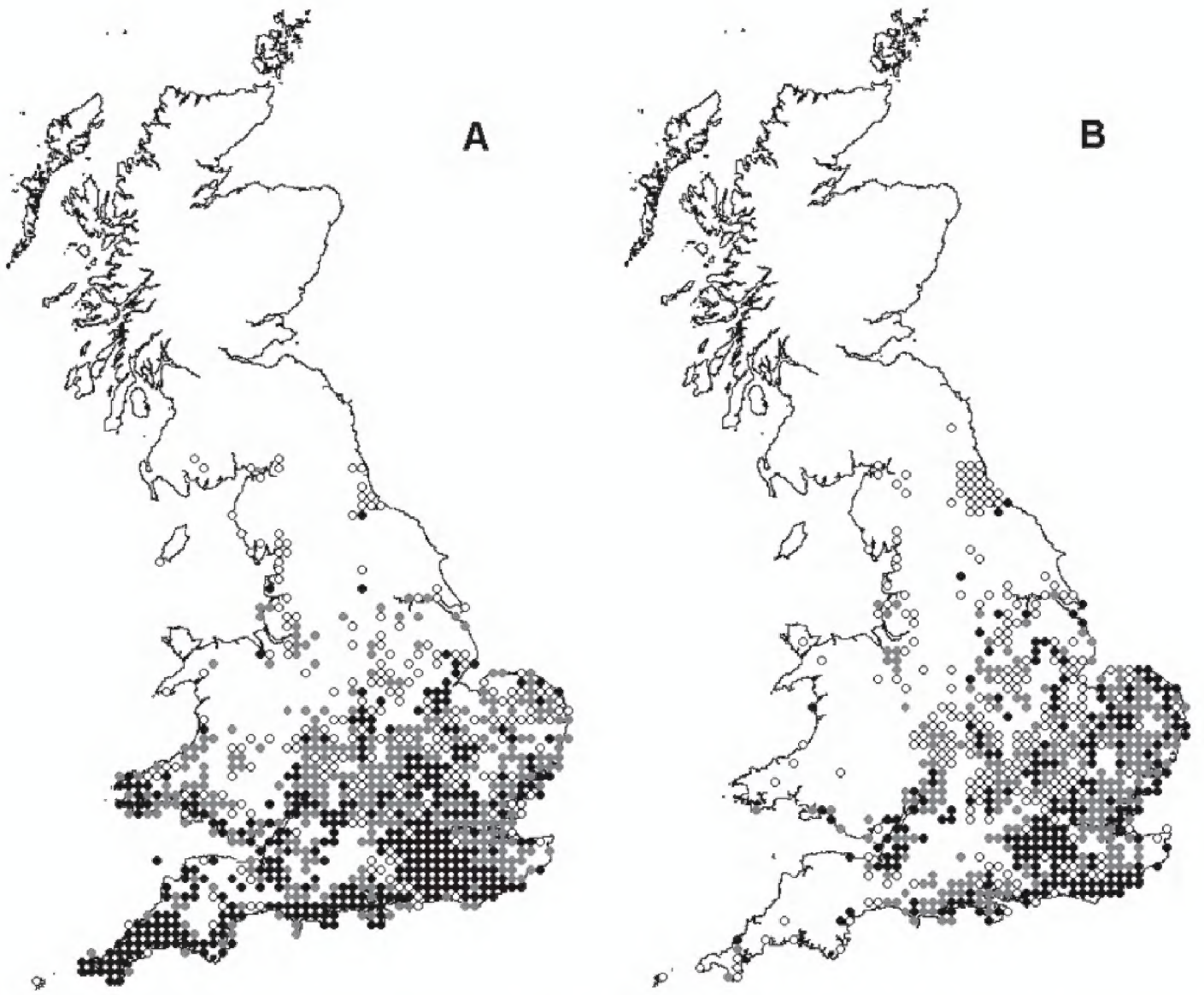


Figure 1. Distribution maps for **A** *Anax imperator* and **B** *Sympetrum sanguineum*. ● First recorded before 1980, ● First recorded 1981–1990, ○ First recorded 1991–2004.

early August 2006 saw the most northerly British records to date, including one from ca. 56°15'N in south-central Scotland (Parr 2007).

Sympetrum sanguineum. Speculation during the 1970s that this species might have been in decline in eastern England was probably exaggerated, earlier records having been biased somewhat by a period of good immigration in the 1930s and 1940s (Merritt et al. 1996). By the late 1980s it was clear that the species was in fact doing well in several areas, and recently the species has been expanding its range rapidly to the north (Fig. 1B). From a northern limit of *ca.* 53° 30'N in 1982, the species has now been recorded right up to the Scottish border, beyond 55° 30'N. Curiously, it still remains rather rare in the far southwest of Britain.

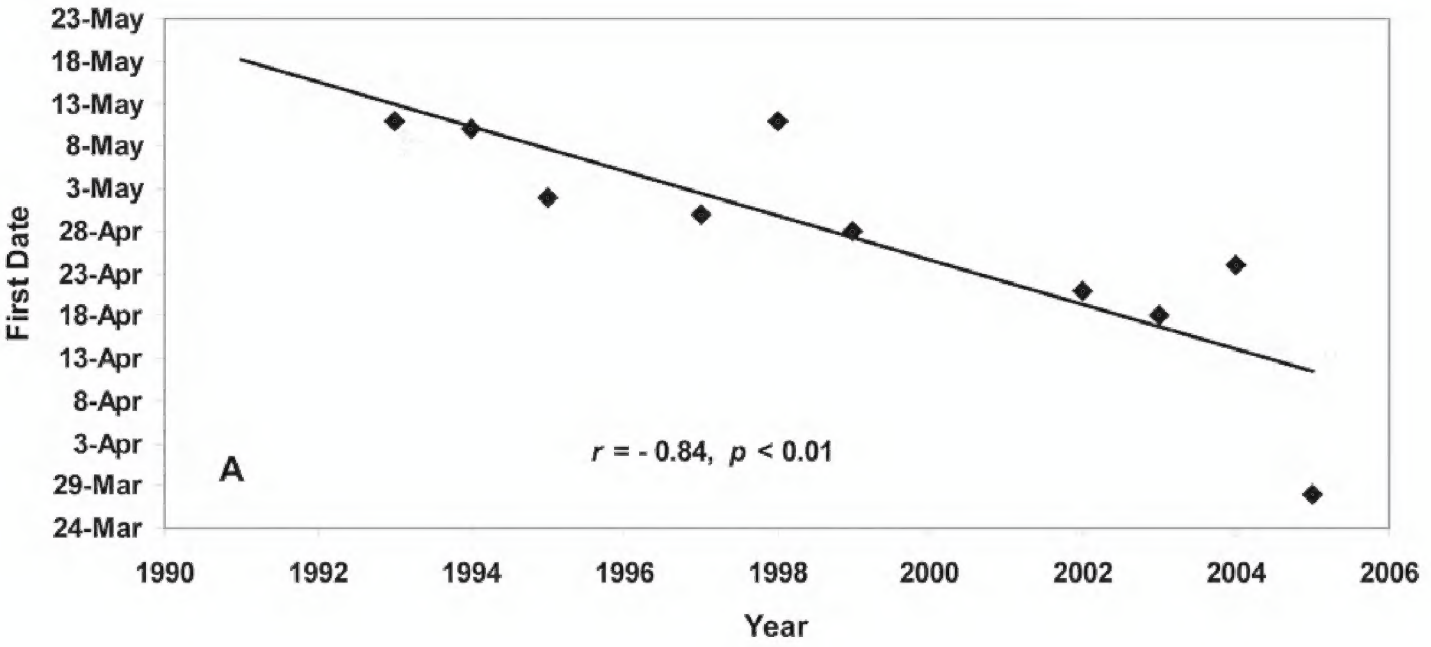
Leucorrhinia dubia. Although the British stronghold of this species has always been in Scotland, there are (or, in some cases, were) outposts in the north of England, the northwest Midlands and the Surrey heaths of southern England. In Surrey the species had been recorded over the years from at least three 10 × 10 km grid squares (Merritt et al. 1996). This southern population is however now extinct, the last individual having been noted at Thursley Common during 1999 (Perrin 2000). Certain other sub-populations have also experienced a decline, in part due to habitat loss (Merritt et al. 1996), though fortunately in places the species continues to do satisfactorily.

Phenology

The British Odonata database now contains nearly 500,000 records, which in addition to allowing the monitoring of distribution, will also contain extensive phenological information. Basic summary data and a preliminary analysis of the effects of latitude and year-to-year variation on phenology have been available for some while (Merritt et al. 1996). More recently, the appointment of a salaried BDS staff-member to work with the database (to ensure that its structure is compatible with the evolving National Biodiversity Network and to extract key data) has facilitated a more extensive analysis of phenological data. It is clear that since 1960 there has been a significant shift in the phenology of the British Odonata as a whole, with species experiencing a continuing advance in the leading edge of the flight period - i.e. they are starting to emerge earlier (Hassall et al. 2007). This correlates strongly with changes in British climate during the same period. On average the forward shift amounts to 1.5 days per decade, though there are indications that spring-emerging species are more strongly affected than those that emerge in summer (Hassall et al. 2007). No general trends relating to the end of the flight period were apparent, perhaps because different species respond differently (Hassall et al. 2007).

In addition to the detailed statistical analysis of the British Odonata database, other approaches to monitoring phenology are also available. For over 15 years, many BDS members have been routinely recording the dates of the first and last sightings of different species in their area, and a database of national 'first' and 'lasts' has been established. Such data has its limitations, but it does have an immediacy that has proved attractive, both for encouraging recorders and for attracting public attention. *Calopteryx splendens* is a useful species to examine in detail. Figure 2 illustrates changes in the dates of reported first and last sightings in Britain over recent years. Although there are a few historic records that are similar to recent extremes, there is a clear trend for the species to now be seen earlier in spring and later into the autumn than before. Indeed in 2005 individuals were recorded between 28 March and 10 October, which is unprecedented for Britain. Detailed analysis of the data is difficult as extreme dates are by definition somewhat atypical, and they are also sensitive to recording effort, with the increasing number of recorders in recent years being more likely to pick up individual rare events. *C. splendens* is however common and relatively large and showy, and is thus readily spotted. It is also easy to identify from a distance. First and last records are therefore less likely to be influenced by observer effects than those for many other species, and it would seem likely that there is indeed an increasing disturbance to what was considered the normal phenology, with both unusually early emergences and either increased adult survival or unusually late emergences now taking place.

Although the analysis of trends in first dates can be problematic, there is one situation where interpretation is easier, namely when one is comparing observations at a single site that has been regularly monitored over many years. Chartley Moss National Nature Reserve, Staffordshire, is one of the major sites for *Leucorrhinia dubia* in England, and the flight period and numbers of individuals seen each year has been closely



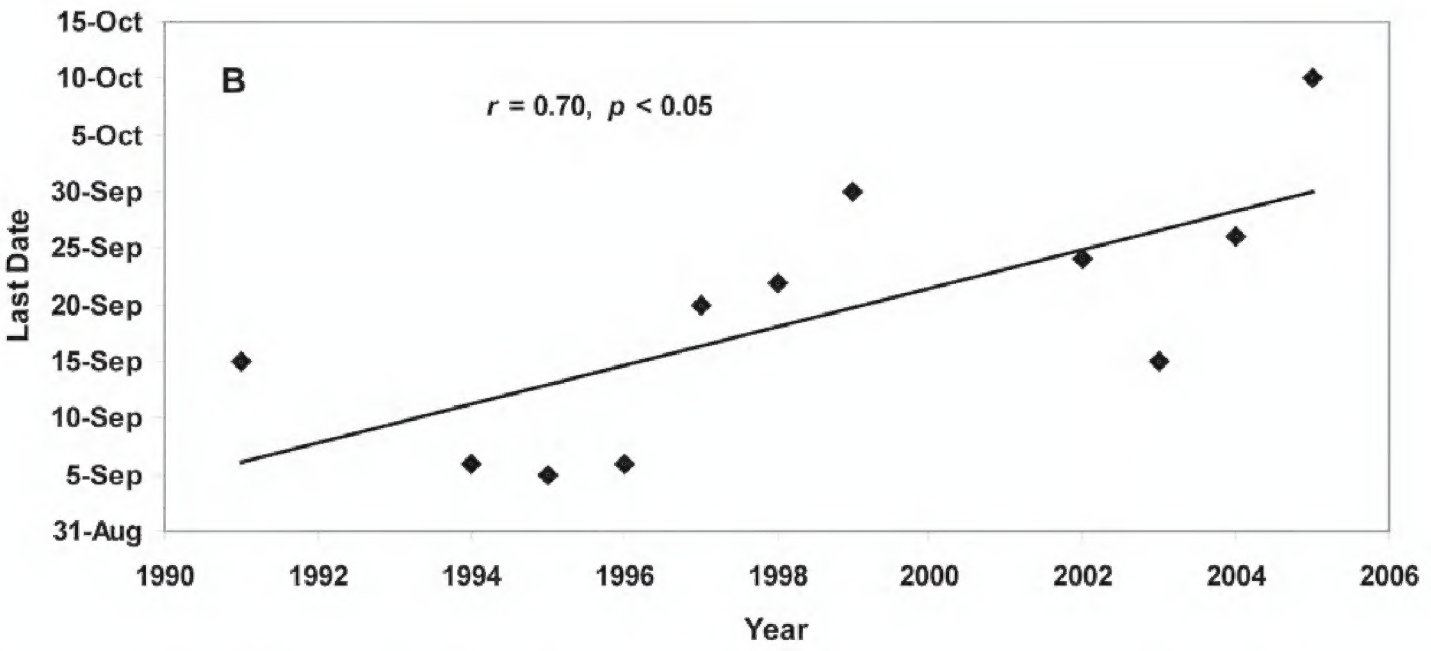


Figure 2. Yearly **A** 'first' and **B** 'last' dates for *Calopteryx splendens* in Britain during 1991–2005.

monitored for two decades. Figure 3A plots the recorded 'first dates' for *L. dubia* during this period; there is a statistically significant ($p<0.05$) trend towards earlier emergences in recent years. Although meteorological data for Chartley Moss itself is not readily available, it lies almost midway between the weather stations of Shawbury and Sutton Bonnington, for which extensive historical data sets exist (Met Office 2006). Analysis shows that over the period of observations at Chartley, both weather stations showed a slight trend towards increases in spring temperature, but this was small in comparison to yearly variation, and was not statistically significant. In itself, such a trend cannot therefore account for the phenological changes. More obvious was an increase in mean annual temperature, with both the mean annual maximum temperature (Tmax) and the mean annual minimum temperature (Tmin) increasing with time. Over the period in question, Tmax showed a mean linear increase of *ca.* +0.06°C per year ($p<0.05$ at Sutton Bonnington, $p<0.01$ at Shawbury - see Fig. 3B), while Tmin showed a mean linear in-

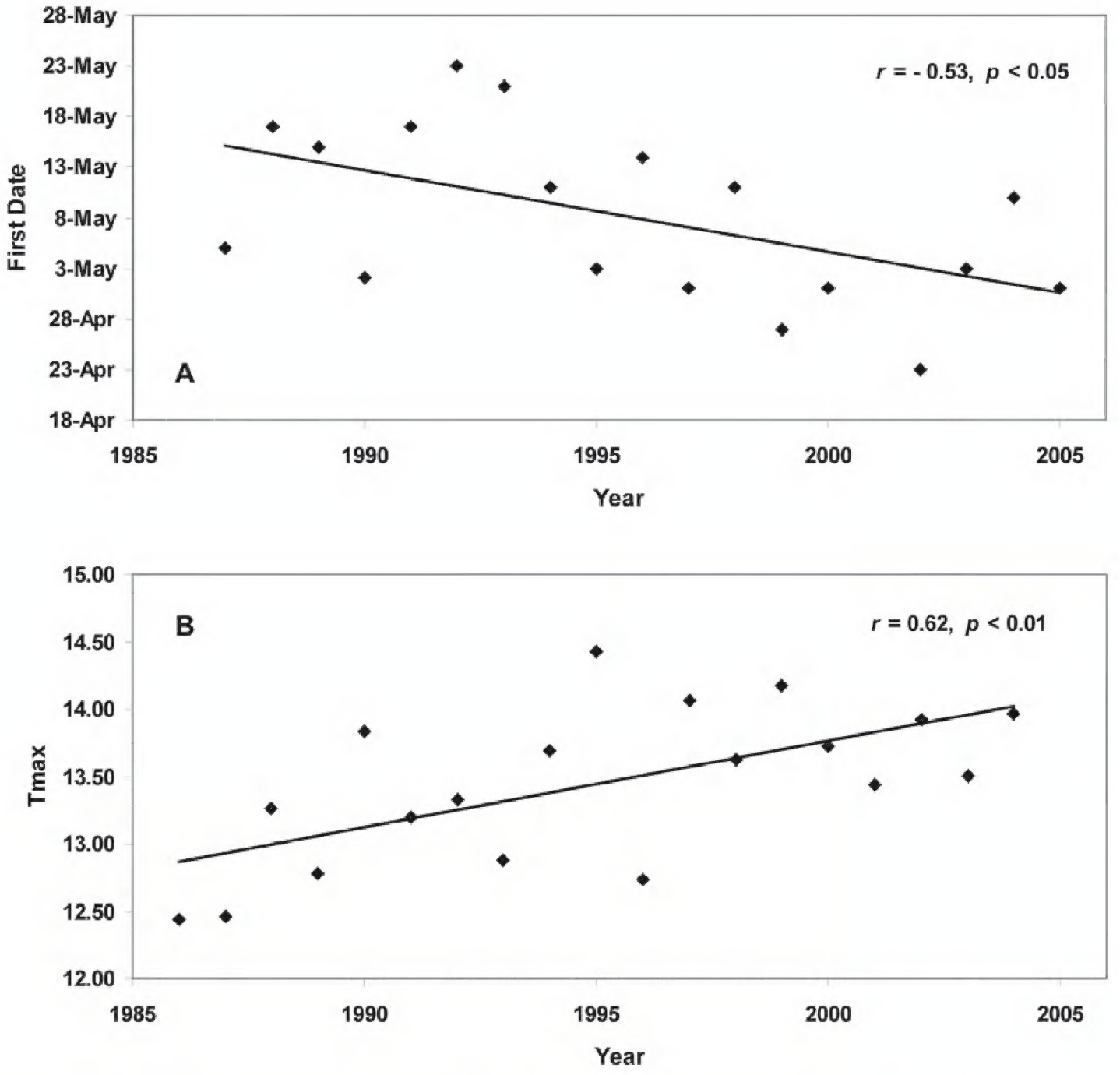


Figure 3. Phenological trends and climate: **A** 'First dates' for *Leucorrhinia dubia* at Chartley Moss NNR, Staffordshire, England, during the period 1987–2005. In most years the site was visited at 2–3 day intervals during the appropriate time period. In 1991–1994 it was only possible to visit weekly, and to avoid bias towards later dates, 'first dates' are here taken as midway between the visit on which *L. dubia* was first recorded and the preceding visit. **B** Mean annual maximum temperatures at Shawbury Weather Station.

crease of *ca.* +0.05°C per year ($p<0.05$). These trends may well account for the observed shifts in spring emergences. In contrast to the results for first dates, the data for late dates was more scattered, principally due to sporadic very late sightings (the latest being 12 October) apparently resulting from unexpectedly late emergences in certain seasons. This could sometimes be linked to poor weather in the early part of the season, but this was not always the case, and perhaps these observations are also of some significance.

In addition to the situation with *L. dubia* alluded to above, other instances of autumn emergences that seem at odds with accepted life-cycle strategies in northern Europe have been documented in recent years. These include September emergences of *Anax imperator* (Parr 1999), the larvae of which are normally considered to have an

autumn diapause to ensure synchronous emergence the following spring (Corbet et al. 1960). In this particular instance the presence of an immigrant population with a different phenology might be one explanation, but further investigation of unexpected autumn emergences might help throw light on changing phenologies in the region. Although such emergences are still rare events, it is, for example, not inconceivable that certain species are starting to show partial changes in voltinism.

Conclusions

It is clear that the British Odonata fauna is currently going through a period of considerable flux:

– Several resident species are currently expanding their ranges, though a few are in regression. Those expanding their range are often species of 'southern' affinity, and are expanding to the north and west, some with considerable speed. The 'northern' *Leucorrhinia dubia* is however contracting its range, having recently become extinct in its southern English outpost.

– Species never before observed in the British Isles are now starting to turn up in the region as they expand their ranges. Again, it is principally those somewhat thermophilic species with a 'southern' distribution in Europe that are involved, although there are exceptions (e.g. the more eastern *Sympetrum pedemontanum* and the American *Anax junius*).

– There is evidence for shifts in phenology, with earlier emergences in spring and at least for some species the suggestion of unusual late season records as well.

In addition to the Odonata, changes are also being observed in the UK for a very wide range of other taxa. Particularly in the case of birds, changes in range and phenology have already been extensively documented (e.g. Thomas and Lennon 1999; Musgrove 2002; Cotton 2003; Eaton et al. 2005). Within the Insect order, it is clear that in addition to dragonflies, several butterflies with a southerly distribution in the UK are also expanding their ranges, though there are signs that habitat limitation may be restricting the number of species involved (Warren et al. 2001). The spread of the warmth-loving sphecid wasp *Philanthus triangulum* has similarly attracted attention (Edwards 2000), as has the spread of the Orthopterans *Metrioptera roeselii* and *Conocephalus discolor* (Thomas et al. 2001). This latter situation is particularly interesting, with the dramatic north-westerly range expansions seen in the last 20 years being facilitated by the increased occurrence of long-winged forms with enhanced dispersive capabilities (Thomas et al. 2001). In addition to these range changes, a wide variety of insect species have recently been recorded in Britain for the very first time. These are too numerous to list fully, but include various moths such as *Thaumetopoea processionea*, *Ochropleura leucogaster*, *Dryobota labecula*, *Spodoptera cilium*, *Platyperigea kadenii* and *Pechipogo plumigeralis* (Waring and Townsend 2003; Clancy 2006), the bee *Bombus hypnorum* (Goulson and Williams 2001), the social wasps *Dolichovespula saxonica* and *D. media* (Edwards 2000), a good variety of Coleoptera including the coccinellids

Rhyzobius chrysomeloides, *Epilachna argus* and *Harmonia axyridis* (Biological Records Centre 2008), and also the hemipteran *Nezara viridula* (Shardlow and Taylor 2004). Although some of these records may represent accidental introductions, many species appear to have reached Britain unaided, in an extension of wider trends.

Since changes being seen in the UK are qualitative as well as quantitative, they cannot simply be artifacts of the increased interest in Odonata and many other areas of wildlife that has taken place in recent years. Rather, the types of change, and their widespread and consistent nature, seem to imply that some high-level controlling variable such as climate is involved, though of course this might operate in a variety of way (e.g. either directly or via effects on things such as habitat quality). Although it is difficult to be precise, recent changes seem to have started in earnest during the 1980s. The early 1980s roughly coincide with the onset (or, more strictly, intensification) of a significant and continuing increase in British, Northern Hemisphere and Global mean temperature (Jones & Moberg 2003; Climate Research Unit, UEA 2008; Hadley Centre 2008). Indeed, for Odonata, the closest historical situation in Britain to that which is currently taking place appears to be the good migrant years of the 1930s and particularly the 1940s (Longfield 1949; Parr 1996). This period was also associated with a phase of steeply rising temperature, though in this case it was not sustained (Jones and Moberg 2003; Hadley Centre 2008). Many current trends would thus appear likely to be linked to climate change.

It will be of considerable interest to continue monitoring changes to the British Odonata in years to come, and the BDS intends to strengthen its resident and migrant recording schemes, develop more detailed studies of dragonfly abundance, and also consolidate its studies on phenology.

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